Figure 1 An experimental setup of this study. The QUASAR^{TM} was on the couch and moved the cube phantom along the longitudinal axis. The O-ring gantry was skewed 30° around its vertical axis.

Results: Results were shown in table 1. The root mean squares (RMSs) of the mechanical control error were within 0.12 mm for each pattern. The RMSs of the beam positioning error were within 0.39 mm for each pattern. The RMS of the beam positioning error in conformal arc irradiation (without dynamic-tumor tracking) was 0.30 mm. This error was mainly due to the set-up error of the cube phantom. The difference of the RMS of the beam positioning error between dynamic tumor-tracking arc irradiation and conformal arc irradiation was within 0.1mm. Therefore the beam positioning accuracy of dynamic tumor-tracking arc irradiation was comparable to conformal arc irradiation.

Table 1 RMSs of mechanical control errorand beam positioning error

	Mechanical control accuracy [mm]		Beam positioning accuracy [mm]
	Pan	Tilt	
Sinusoidal wave	0.04	0.10	0.37
Patient's regular wave	0.04	0.12	0.39
Patient's irregular wave	0.03	0.08	0.38

Conclusions: The beam positioning accuracy of dynamic tumor-tracking arc irradiation with the gimbaled x-ray head was evaluated and the feasibility of this technique was suggested.

PO-0872

Evaluation of a novel anti-scatter grid for CBCT guided radiotherapy

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Purpose/Objective: Cone beam CT (CBCT) systems mounted on a medical linear accelerator provide useful soft tissue contrast for image guidance in radiation therapy. Presence of extensive scattered radiation induced by the wide cone angles, however, reduces low contrast visibility. The purpose of this study was to evaluate the impact of a novel fiber-interspaced anti-scatter grid (ASG) on image quality in comparison with currently applied software correction.

Materials and Methods: The evaluated ASG (kindly provided by Philips Medical Systems, Best, The Netherlands) mounted on a Synergy treatment machine(Elekta, Crawley, UK) had a grid ratio (height of lead/spacing between two lead strips) of 21:1 and a grid frequency of 36 lp/cm. Transmission of primary radiation was measured to be 71% at 120 kVp. The device was tested on phantom and in clinical practice. Phantom used was CIRS CBCT Electron Density& Image Quality System (CIRS, Norfolk, Virginia, USA). The phantom was scanned in the standard configuration (representing pelvic scans) as well as in modified configuration to represent head and neck scans.Evaluation parameters were contrast-to-noise ratio (CNR) and signal non-uniformity (SNU). Four scatter correction strategies were tested: no correction, software only, ASG only and finally ASG with software correction adapted to grid use. The imaging dose was not changed when the grid was mounted.

Results: The CNR improved by a factor of 2, 2.8 and 3.2 with software scatter correction, ASG and ASG+software correction respectively, relative to no correction. SNU was reduced from 12.9% in case of no correction to 0.3% with software correction, 1.2% with grid and 0.2%with grid and software for the 'head and neck' phantom. For 'pelvic' phantom the corresponding values were 13.7%, -6.6%, 1.1% and -1.83%. These numbers show robustness of grid compared to software scatter correction. Patient images also showed clinically relevant improvements in terms of uniformity and soft tissue visibility (Fig 1).

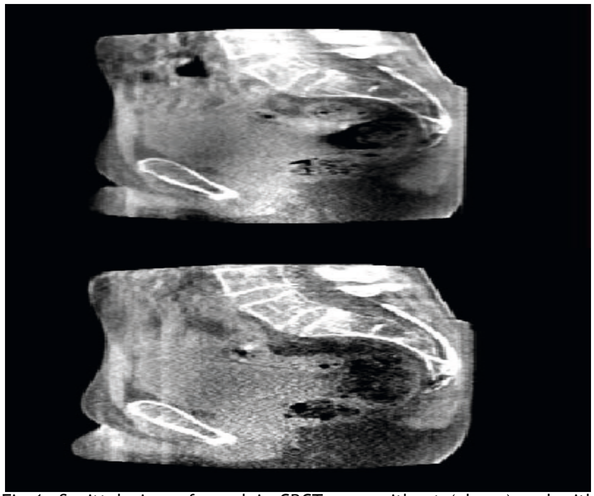

Fig 1. Sagittal view of a pelvic CBCT scan without (above) and with the grid (below). Both images also used software scatter correction.

Conclusions: The evaluated novel fiber-interspaced ASG considerably improved the image quality of linac integrated CBCT scanner without increasing the imaging dose contrary to previous state of the art aluminium-interspaced ASGs. Work continues to optimize the grid parameters and adapt correction algorithms for the residual scatter transmitting through the grid, as well as evaluating the grid in an observational study.

PO-0873

Evaluation of an intrafraction 4D cone-beam CT (CBCT) imaging system

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Purpose/Objective: We have evaluated an intra-fraction cone-beam CT (CBCT) imaging system, XVI 5.0 research unit (Elekta, Crawley, UK) that allows concurrent 4D imaging during volumetric modulated arc therapy (VMAT).

Materials and Methods: During a single-arc stereotactic VMAT delivery for a lung tumor, a 4D CBCT projection data for a 4D phantom were acquired using the XVI unit. The 4D phantom was operated by a controller accepting arbitrary 4D input data. The XVI unit calculated 10-phase binned 3D volume data and the resulting 10-phase binned breathing trajectory was stored in the XVI unit. The 4D coordinates calculated by the XVI unit were compared to the 4D input data stored in the phantom controller. For our test, the following trajectory functions were employed to three orthogonal directions.

AP: 10*sin^2((t/3.4-0.02)*Pi)-2.2, SI: 10*sin^2((t/3.4-0.49)*Pi)-43, LR: 10*sin^2((t/3.4)*Pi)-56

Results

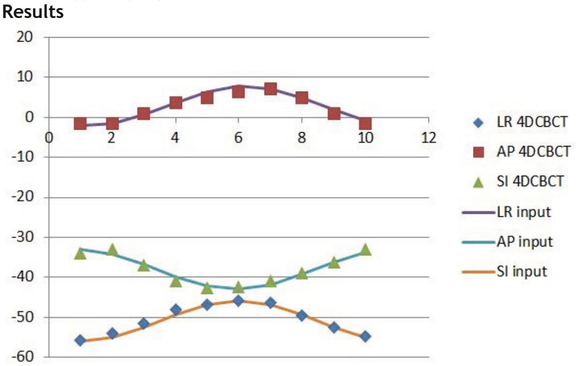

Figure 1 compares acontinuous tumor trajectory according to the above formula to 10-phase binned trajectory data computed by the XVI unit. The resolution was 0.5 mm because the volume matrix size was 128 x 135 x 135. Within this precision, good agreement was obtained.

Conclusions: We have confirmed that the XVI 5.0 research unit accurately calculated 10-phase binned 4D phantom positions during

VMAT delivery. Our next step is to acquire a real tumor trajectory for a lung cancer patient using a 320-row CT, which will be fed into the phantom controller for our further validation.

PO-0874

Effective and organ doses from Cone-Beam CT

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Purpose/Objective: Kilovoltage cone-beam CT (CBCT) devices allow image guidance before radiotherapy treatments. Cone beam introduces more scatter radiation than a conventional CT scanner. In this study, the more suitable Cone Beam Dose index (CBDI) was measured instead of CT Dose Index (CTDI), in order to have a better evaluation of the average volumetric dose from the CBCT in the CTDI phantom. CBDI was measured and used to estimate organ and effective doses from CBCT using two MonteCarlo software.
Materials and Methods: Three standard CTDI head phantoms and a Farmer chamber (according tothe AAPM Report 111) were used to measure the CBDI form an Elekta XVI (ver.4.2.1). The CBDI measurements were performed using two protocols. Protocol 1 is used in clinics to verify patient setup in the treatment room.The parameters are: 36.1 mAs, 100 kV, 200° rotation angle and S20 collimator (small FOV). Protocol 2 is the one we use for replanning to obtain a better image quality. It works with 647 mAs, 120 kV, 360° rotation angle and M20 collimator (medium FOV). The scatter contribution on the CBDI was measured using two phantom set-ups and the Protocol 2. In the first setup the chamber is placed in the central hole of one phantom. In the second set-up the chamber was inserted in the central phantom of three aligned in the longitudinal direction. This configuration was used as reference for dose simulation because it better simulates the patient scatter conditions, and the $CBDI_w$ was calculated using the formula $CBDI_w = 1/3CBDI_{center} + 2/3CBDI_{periphery}$.
Two simulation software requiring different input parameters were used for the estimation of the effective and organs at risk dose in the Head&Neck district. CTDosimetry software (ver. 1.0.4 ImPACT, London, UK)uses the $CBDI_w$ measurement with mAs, kV and scan region. PCXMC2.0Rotationsoftware (STUK, Helsinki, Finland) uses geometrical and protocol parameters including the rotation angle. The two software use a mathematical phantom based on the Cristy's hermaphrodite phantom, and dose calculation is based on the ICRP 103 Report.
Results: The percentage difference between the CBDI measured with the first and the second setup was 11%. MonteCarlo data showed an overall dose accuracy lower than 15%. An effective dose of 0.15 mSv for Protocol 1 and of 4.4 mSv for Protocol 2 was calculated with CT Dosimetry software. Using the PCXMC2.0 Rotation software it was obtained the same result for Protocol 1 and an effective dose of 3.2 mSv for Protocol 2. We got quite similar results for organs at risk as reported in Table 1.

Table 1	CTDosimetry		PCXMC2.0Rotation	
OARs	Protocol 1 dose (mGy)	Protocol 2 dose (mGy)	Protocol 1 dose (mGy)	Protocol 2 dose (mGy)
Active Marrow	0.14	4.4	0.13	3.3
Oral Mucosa	1.2	36	1.4	29
Salivary Glands	1.2	36	1.4	34
Thyroid	1.6	46	1.8	33

Conclusions: CBCT imaging using cone beams adds a dose uniformly distributed over a wide field of view, often including OARs. Since radiotherapy CBCT imaging could be a daily practice, the imaging dose delivered to OARs can reach considerable values. Therefore this extra dose should be evaluated and taken into account in the overall treatment plan in order to report the real OARs dose.

PO-0875

Patient specific scatter distributions in CBCT imaging calculated by Monte Carlo simulations

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Purpose/Objective: Cone Beam CT (CBCT) image quality is limited by the presence of scattered photons. Monte Carlo (MC) simulations provide a powerful tool for predicting patient specific scatter distributions. The time needed to perform such simulations can be a limiting factor preventing the use of MC simulations to correct for scattered photons in clinical CBCT imaging. This project investigates the feasibility of using a planning CT image to calculate the scattered photons that will be present in CBCT images acquired during radiotherapy.
Materials and Methods: The EGSnrc user code egs_cbct was used to perform MC simulations predicting scatter distributions in a head, thorax and pelvis CBCT scan. Simulations were based on planning CT images, and the simulation setup was designed to mimic an Elekta XVI CBCT imaging system operated without a bowtie filter. A monoenergetic x-ray source was used, and air KERMA was scored for each projection image simulated in steps of 1.25 degrees. No downsampling of the planning CT images or the CBCT detector resolution was performed compared to the clinical setup used in our institution. Simulations were run on a 24 CPU cluster.
Results: Taking advantage of the variance reduction techniques available in egs_cbct, scatter distributions can be predicted within 2% statistical uncertainty in less than 30 minutes for the head scan, 60 minutes for the thorax scan and 120 minutes for the pelvis scan. Image quality is significantly improved in MC simulated CBCT images without scatter, compared to simulated CBCT images with scatter. The simulated number of histories, statistical uncertainties and simulation times are shown in the table. The reduced simulation time and statistical uncertainty in the head scan is due to the shorter path length and hence less attenuation of the x-rays compared to the larger patient volumes simulated in the thorax and pelvis scan. The denser pelvic region compared to the thorax requires the lengthiest simulations to compensate for the increased attenuation of x-rays.

	Head	Thorax	Pelvis
N_{hist}	5×10^4	5×10^4	10^5
σ_{max}	1.3 %	1.5 %	2.0 %
T_{CPU}	23 min	50 min	120 min

Conclusions: Recent MC software allows the prediction of patient specific scatter distributions in clinical CBCT imaging to be performed in a time frame enabling clinical applications. Simulations are based on planning CT images, and the varying simulation time for different anatomical regions is explained by variations in patient volume and density. MC simulations show a great potential for improved CBCT image quality if scattered photons can be removed more efficiently than the current clinical practice allows. For each patient, only one MC simulation is necessary to improve all CBCT images acquired during multiple radiotherapy fractions.

PO-0876

Fiducial registration error in prostate and its influence on target registration error

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Purpose/Objective: Target registration errors after MR-CT-fusion are challenging to classify. The standard procedure in our clinic is to implant 4 gold fiducials in the prostate, and a MR-CT-fusion is then performed based on a rigid registration of the 4 gold fiducials. The implantation procedure states that the urologists should implant one apically, one centrally, and two in the base at different depths, guided by ultrasound. The implantation can be of mixed quality, and not all fiducials are implanted in the prostate. The aim of this study was to assess how the fiducial registration error (FRE) correlated with